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STUDIES OF THE BLACK-ROT OR BLIGHT DISEASE OF CAULIFLOWER

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STUDIES OF THE BLACK-ROT OR BLIGHT DISEASE OF CAULIFLOWER

E. E. CLAYTON

ABSTRACT

The author presents here the results of seven years' investigation of the cauliflower black-rot (*Bacterium campestre*) on Long Island. The principal subjects treated are: The overwintering of the disease in the field; the manner in which the seed becomes infected; the development of the disease in the seedbed and in the field; the relation of weather to the disease; the ways in which the disease is spread; and methods of control. Under the last-named topic there is included a discussion of the nutritional and cultural factors involved, the removal of diseased plants and leaves, spraying, dates of planting, resistant varieties, weeds as sources of infection, selection of soil for the seedbed and the field, and seed disinfection.

The conclusion is reached that we now have a thoroly practical method for the control of black-rot in cauliflower. Essentially, it consists in treating the seed with hot water and locating the seedbed on disease-free soil.

INTRODUCTION

In 1922, when the writer began work on Long Island, the outstanding disease problem presented by the growers for solution was the black-rot disease as it attacks the cauliflower crop. Other crucifers extensively cultivated on the Island were cabbage and brussels sprouts, but, tho the trouble was common with these crops, the damage done was slight and losses negligible. The cauliflower growers, however, feared that, owing to heavy and continued losses from black-rot, or blight as it is called, the industry was doomed. They recognized two phases of the trouble, first, the blight in which the leaves, riddled by numerous lesions, dried up and dropped off; second, the stump-rot where blighted fields, following a few days of humid weather, were attacked by soft rot and often the entire crop destroyed in a short time.

The disease was no recent development in the Long Island cauliflower industry but appears to have increased steadily in destructiveness. However, Lupton (10),[3] a leading Long Island cauliflower grower, wrote in 1894 that, "excessive humidity in the atmosphere frequently develops a disease of the stalk called stem-rot which sometimes destroys whole fields and for which we have no known remedy; but if the weather be cool during August with occasionally a cool rain to keep them coming along, we can expect a good crop."

The destructiveness of black-rot in quite another section of the country was noted by Taft, Gladden, and Dean (16) who stated in 1899 that in Michigan, "the bacterial black-rot of cabbage attacked the late varieties quite badly, completely destroying several sorts and checking the growth of others to an extent that made it impossible to find typical specimens for description."

The first scientific studies of the disease were made by Smith (14) and by Russell (12). The results of their studies were most interesting and productive of many suggestions for control. Thus, Smith recommended as follows:

1. The seedbed should be made in a different place each year.
2. Set plants on land which has not been in cabbages or other crucifers for some time.
3. As a matter of precaution avoid the use of stable manures, since these may possibly serve as a means of carrying the disease into uninfected fields.
4. Do not turn animals into diseased fields and then allow them to wander over other parts of the farm.
5. All farm tools used in infected lands should be scoured bright before using on uninfected land.
6. Keep up constant warfare against insect enemies, especially the cabbage butterfly and the harlequin bug.
7. As a palliative, remove badly infected plants from the field as fast as they appear. In early stages of the disease, *i. e.*, while it is still confined to the margins of the leaves and has not yet entered the head or stump, go over the fields systematically about once every ten days and break off and remove all the affected leaves.
8. Weeds which harbor the disease, especially the wild mustards, must be destroyed systematically.

Twenty years after the above was published Harter and Jones (9) made the following recommendations for black-rot control:

1. The germs are known to be carried on the seed; therefore all seed should be disinfected before sowing.

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[3]Refers to Literature Cited, page 43.

2. Care should be exercised in the preparation of the seed-bed, and only manure and soil should be used that are known to be free from disease.

3. Crop rotation, whether for the prevention of the disease or not, is always good practice. To control the disease by this method the rotation should be one in which no cultivated crucifers or cruciferous weeds are allowed to grow for five or six years.

4. Insects, slugs, snails, etc., by crawling from infected to non-infected plants, carry black-rot organisms; when possible they should be kept in subjection.

5. Livestock should not be allowed to roam at will over diseased cabbage patches, as they may carry the organisms to the non-infected fields.

6. Diseased plants, as soon as detected, should be pulled up and destroyed and not thrown on the manure heap to compost.

Comparing the two, it is noted that both recommend:

1. Utmost care in preparation of the seedbed to avoid soil contamination.
2. Crop rotation.
3. Insect control.
4. Livestock "control."
5. Pulling and destroying diseased plants as soon as they appear.

In fact the only addition that Harter and Jones make to the original recommendations of Smith is the disinfection of the seed.

Such unanimity, however, does not, in this instance, mean that the control measures as outlined have given satisfactory field control of black-rot, for the Long Island cauliflower growers in 1922 were using the most up-to-date practices, including seed disinfection, and yet were being ruined by regular heavy epidemics of the disease. As a matter of fact Harter and Jones state that, "it is to be regretted that no sure methods of controlling black-rot are known, but the observance of certain precautions will prevent serious loss from this very destructive disease." The experience of Long Island growers was fully in accord with the first part of this statement but not with the second.

In attempting to ascertain the causes for failure to control black-rot on Long Island, an extensive field survey was conducted during the seasons of 1922 and 1923. Some of the findings from this work are noted below.

Cabbage and brussels sprouts grown on the same fields with cauliflower were in no case suffering serious injury from the black-rot disease notwithstanding the fact that the cauliflower was often a complete loss. This agrees with Russell's (12) statement that, "the cauliflower is most

susceptible, frequently acquiring the disease under conditions where cabbage shows only a mere trace or entire absence of it."

Most of the cauliflower seed had been given the bichloride of mercury treatment before it was purchased, but the fields grown from this treated seed were as badly diseased as those grown from untreated seed.

The fields planted, almost without exception, had grown no cauliflower for from 4 to 15 years and some of the most severe losses were in fields that had grown noncruciferous crops for as much as 10 and 15 years. The seedbeds were usually located in the fields and hence received the same rotation. Numerous examinations of plant beds failed to discover the presence of black-rot prior to the time of plant setting, except in a few instances.

As the result of this survey, the only conclusions arrived at were: First, that the cauliflower, due to greater susceptibility, was destroyed by the disease under conditions such that cabbage and brussels sprouts were but little injured; and, second, that mercuric chloride seed treatment, plus rotation, was not controlling the disease.

OVERWINTERING OF DISEASE IN THE FIELD

The writer has found that this disease lives over very freely in cabbage plants that have been held over winter in trenches for seed growing as previously noted by Harding, Stewart, and Prucha (8). In addition, observations made in many old plant beds showed that brussels sprouts and cabbage plants frequently survive until spring and among these are often black-rot infected individuals. Such diseased plants show evidences of the infection on the newly formed leaves just as soon as the weather becomes warm. The black-rot organism has been repeatedly isolated from the old discolored stems of these plants and the pathogenicity of the cultures proved by inoculation into healthy seedlings. In a similar manner cabbage and brussels sprouts plants in the field sometimes survive the usual Long Island winter in considerable numbers, and the organism has been frequently isolated in the spring from the stems of such plants. The importance of these plants that live over in the seedbed and fields as sources of primary black-rot infection is not great when the rotation is wide. Instances have been observed, however, where the previous year's crop of brussels sprouts was turned under in the spring and a new crop set out the same summer. In several such cases the heavy developments of black-rot that resulted were undoubtedly due to infection carried in the overwintering plants.

In one case a field under observation grew a crop of brussels sprouts that showed considerable black-rot and the following spring many of the diseased plants were still alive. These were permitted to grow for a month in the early spring, at the end of which time many had active black-rot infections. The field was then disked and plowed and later set with brussels sprouts again. When examined six months after planting, between 25 and 30 per cent of the plants already had black-rot in their stems. Nearby fields, set on new ground, showed in no case more than 0.5 per cent of the black-rot infection at this time. Thus the ability of the organism to live over winter inside the surviving host plants is well established.

Cauliflower plants, however, do not live over winter, and in the principal cauliflower growing sections comparatively small amounts of cabbage or brussels sprouts are grown. Consequently, the next question was the ability of the black-rot organism to live over in the dead tissues of the cauliflower plant. Monteith (11) states that, "clean seed, sown in sterilized soil mixed with diseased cabbage leaves which had been exposed to a Wisconsin winter, yielded seedlings with a high percentage of infection." Altho it is not so stated, the presumption is that the cabbage leaves were dead and that the bacteria persisted in the dead tissues.

The writer first attempted to isolate the organism from the stems of diseased cauliflower plants that had stood in the field over winter. Individuals were selected that were in the best condition and in which the blackened vasculars could be clearly seen. All such attempts, however, yielded other bacteria in abundance but not *Bacterium campestre.* Continuing the work with the overwintered cauliflower plants, a good sized load was collected and brought into the greenhouse in March. There, a lot of cauliflower plants growing in sterilized soil were inoculated by wetting the leaves and sprinkling with the pulverized plant remains. The plants were then kept moist in an inoculation chamber and held at warm temperature. That the conditions were favorable for black-rot was proved by inoculating checks with pure cultures with the result that the disease developed rapidly. None of the several hundred plants inoculated with overwintered plant refuse, however, developed a single black-rot lesion. Alternaria (*A. brassicae* (Berk.) Sacc.) appeared freely.

At the same time that the previous test was being made, more of this old cauliflower material was mixed with soil and filled into flats. Seed

was sown and plants grown. The seedlings grown in the refuse were surprisingly healthy and there was no disease development with the exception of a small amount of damping-off. Several thousand of these seedlings were carried for six weeks without any black-rot developing. Continuing the effort to secure black-rot infection from this old cauliflower refuse, a plat of soil out of doors was spaded up and a large quantity of the refuse worked into the soil. A check plat nearby without refuse was also prepared. The plats were sown with disease-free seed and carefully watched for two months. Several suspicious-appearing lesions were cultured but no black-rot was found. In the plat to which refuse was added, however, the plants were very severely attacked by peppery spot (*Bacterium maculicolum* McCulloch) and Alternaria spot, while the plants of the check plat remained free from these diseases. That the condition during this out-of-door test were favorable for the development of black-rot was proved by the fact that the disease developed freely in other field plats. In summary, then, the results of the successive greenhouse and field tests this season failed to demonstrate the presence of any black-rot infection in the dead stalks and leaves of the overwintered cauliflower plants. The disease, however, overwintered freely in living cabbage plants held over in trenches for seed production and in cabbage and brussels sprouts plants that survived in the plant beds and fields.

The negative results secured in the previous experiments with overwintered cauliflower plants led to a continuation of the experiments. While the conclusion was reached that the organism does not find the dead leaves and stalks of cauliflower plants congenial places in which to live over, it did not follow that the soil in one-year-old fields was also free from infection. To secure definite information on this point, two areas, each 20 x 40 feet, in a very badly diseased field were enclosed with boards the following spring. One of these areas was sterilized with formalin, using 500 gallons of a 1 to 50 mixture applied in two portions, and thoroly soaking the ground to a depth of 6 inches. In the other area the soil was left untreated. Seed grown in the greenhouse and known to be disease-free was sown 10 days later. The seed sown in the treated and untreated soil germinated well and a good stand of plants was secured. However, germination in the untreated area was quicker and the plants grew more rapidly than in the treated area.

Four weeks after planting, several lesions that proved to be black-rot

appeared in the leaves of plants grown in the untreated soil, while none were found in the treated plat. About the same time rhizoctonia and peppery spot made their appearance and caused considerable damage in the untreated plat. There was a small amount of rhizoctonia and no peppery spot in the treated plat. Five weeks after seed sowing, the plants were pulled and counts of black-rot made as follows: In the formalin-treated plat, 0; in the untreated plat, 18. Counts of rhizoctonia made at the same time showed the following: In the formalin-treated plat, 6; in the untreated plat, 55. No counts were made on peppery spot since 100 per cent of the plants in the untreated plat were infected and only a few lesions were present in the disinfected plat.

As a further check on the presence of black-rot infection in this soil, healthy plants were set in the field and kept under close observation. Some of the same lot of plants were also set in a nearby field that had not grown a previous crop of cauliflower. The plants in the old cauliflower field started to grow normally and showed no infections for several weeks. Following a warm rain on August 10, however, a sprinkling of disease appeared thruout and the disease spread rapidly until all the plants were infected. The check planting on land not previously cropped to cauliflower showed no black-rot infection until late in the season and then only a few lesions. The ability of the organism to live over one winter in the soil was thus definitely established.

BLACK-ROT SEED INFECTION

In addition to overwintering in the field, this disease is known to be seed-borne. The presence of the bacteria on the seed was first proved by Harding, Stewart, and Prucha (8) who showed that the germs were on the surface of seed threshed from diseased plants and further demonstrated that it was possible to secure pathogenic cultures of *B. campestre* from surface-inoculated seed after it had been held eleven months. Subsequent observations have abundantly confirmed the seed-borne nature of the infection and imported cabbage seed has been found to carry the germs. Thus, Walker and Tisdale (17) reported a serious epidemic which was traced to two lots of imported cabbage seed. All of the cauliflower seed used on Long Island is imported and comes from sections of Europe that also export cabbage seed; consequently, the writer was led to make a careful study of seed infection. The original investigation by Harding, Stewart, and Prucha showed that seed may become infected during threshing by the bacteria lodging

on and adhering to the seed surface, and since it was proved that they could live there for some time, the matter was carried no further. If the germs are present only as a surface contamination, the treatment recommended—soaking 15 minutes in a 1 to 1,000 mercuric chloride solution—should be entirely effective. If, however, a condition should prevail such as occurs in the bacterial disease of beans, where there are pod lesions and penetration of the seed coat, then this treatment would not be effective, and the failure of the above treatment to control the disease in Long Island cauliflower fields indicated that something was wrong.

Since it is not possible to grow cauliflower seed out of doors under Long Island conditions, seed was sown in the greenhouse about mid-September. The heads formed by the first of the year and seed was matured by the first of May. The seed plants were grown in 3-gallon crocks so that they were readily moved about. During each of the three years that inoculation experiments were conducted, a double-walled cloth chamber large enough to hold a number of seed plants was constructed. The plants to be inoculated were placed inside (Fig. 1) and sprayed with cultures of the bacteria several times and then kept in a saturated atmosphere for two days before returning to ordinary greenhouse conditions. Temperatures around 75°F were maintained. In many of the experiments young plants in pots as well as the seed plants were inoculated.

The results of these inoculation experiments were very consistent. Six days following inoculation no evidences of infection were seen and then on the 7th day small water-soaked circular spots began to appear on the very young seed pods. The number of lesions continued to increase for several days as older pods showed the infections. The spots soon darkened, becoming almost black at seed maturity (Fig. 2A), and also slightly depressed. The lesions often involved one or more vascular elements of the seed pods and, in these, the bacteria would spread some distance lengthwise of the pod, causing the characteristic blackening. As indicated, the infections appeared first on the youngest pods and also were most numerous there. Thus, two plants, one with pods half grown and the other with pods fully grown and beginning to ripen, were inoculated simultaneously. Accurate counts showed 2.06 lesions per pod for the young plant and 0.31 lesion per pod for the older one. That the difference was purely a question of age was proved by the fact that a young branch on the old plant bearing a crop of young

pods showed 2.12 lesions per pod. Both of the seed plants, in addition to showing lesions on the seed pods, developed numerous "fleck-like" spots on the pedicels of the younger pods, but these spots never enlarged and apparently were abortive infections.

The leaves of the seed plants were old and tough and rarely became infected. Healthy, vigorous-growing young plants, which were inoculated along with the seed plants always developed marginal lesions, but the minimum time required for the appearance of such lesions was 12 days. Hence, under the condition of these experiments, the minimum incubation period for the pod lesions was five days less than that required for leaf lesions and where leaf lesions were numbered by the dozen, pod lesions were numbered by hundreds. A hundred pods selected at random from one crop showed 366 separate black-rot lesions.

Fig. 1.—Cauliflower Seed Plant Ready for Inoculation.

Growing in a 3-gallon crock and standing in a double cloth-walled inoculation chamber ready for inoculation by spraying with a water suspension of *Bacterium campestre*. (Much reduced.)

Not infrequently over 20 separate lesions have been counted on a single pod.

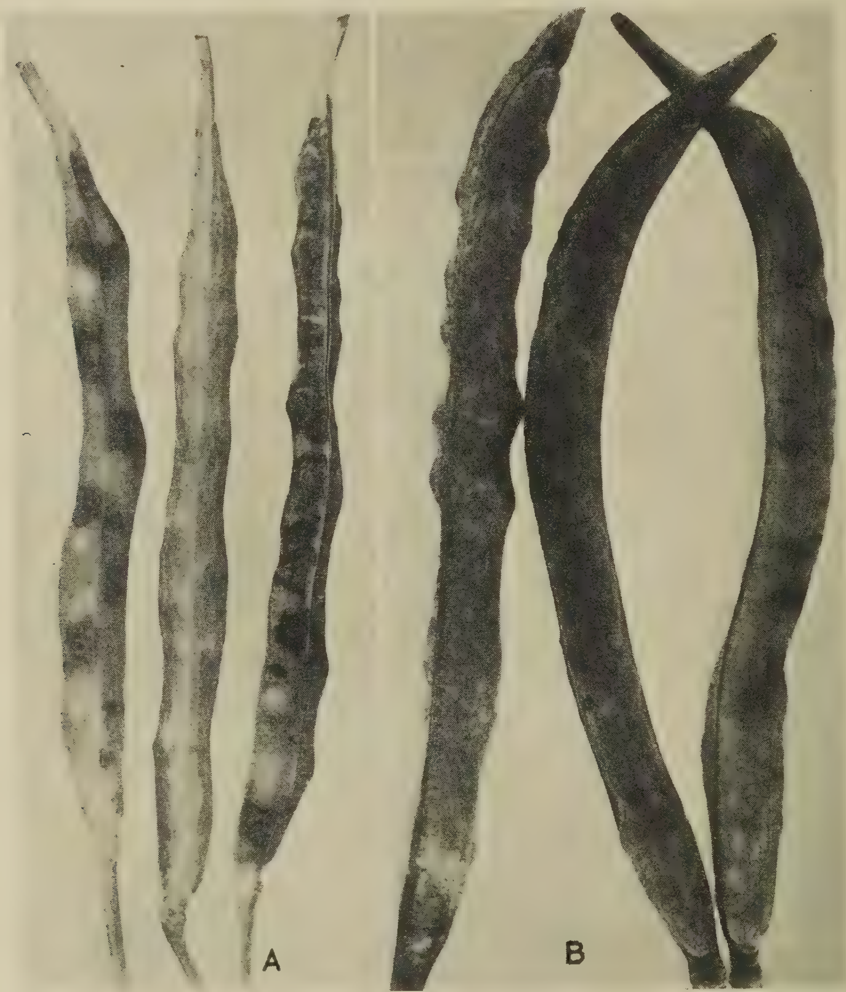

Fig. 2.—Seed Pods of Cauliflower (A) and of Red Cabbage (B). Showing black-rot lesions the result of spraying pods as shown in Fig. 1. In A the center pod is a check. Diseased pods such as these produce seeds which are diseased but viable. The cabbage pods in B were inoculated in the same manner and at the same time as the cauliflower pods in A. Because of the dark red zone surrounding them the spots appear larger than they really are. Cabbage pods are more resistant to infection than cauliflower pods. (Somewhat enlarged.)

In isolating the causal organism from infected seed two procedures were followed: First, the culturing of the organism directly from the seed, and, second, the culturing of the organism from plants produced by infected seed. Examination showed that where the vasculars of the pod suture were infected the infection traveled lengthwise, reaching the seeds attached to the infected suture. (The seeds of crucifers are attached alternately to the opposite sutures.) Also, the seed produced directly beneath a pod lesion showed browning. In neither case, however, was the seed ever destroyed, as is the case with black-leg where the fungus completely destroys many seeds as well as invading, but not killing, others. The germination of seed from pods badly spotted with black-rot lesions was always as high as that of healthy seed.

The procedure in isolating was to disinfect the seeds for a minute in 1 to 1,000 mercuric chloride solution, wash in sterile water, crush in petri dishes, and pour the plates with agar at 45°C. About 15 per cent of the seeds taken from beneath pod lesions gave pure cultures of *B. campestre* under these conditions. Considering seed attached to diseased vasculars, a less common form of infection in these experiments, about 50 per cent of the seed tested yielded *B. campestre*. As to persistence of the organism in seed, the writer has recovered *B. campestre* from three-year-old seed and proved the pathogenicity of the cultures.

The results secured from the planting of seed from infected pods can be best described by giving the details of one experiment. On April 9, seeds from a lot of dry mature pods were picked out carefully and divided into "infected" and "clean", the former coming from beneath pod lesions. A third lot of seeds from healthy pods was included. The seeds germinated well and all three lots grew equally well until April 23 when a typical black-rot lesion appeared in the sinus of a cotyledon (Fig 3). At this time 30 plants from infected seed and an equal number from clean seed were potted. Between April 23 and 30, three more of these plants from infected seed developed black-rot; in one case both cotyledons were infected and, in the other two, a single cotyledon. By May 8 one of these four plants had developed systemic black-rot with two of the true leaves partly wilted. The other three plants, however, were apparently growing normally, so they were dissected.

Plant 1 showed vascular discoloration about the cotyledon scar, but it had not progressed either up or down the stem. Isolations yielded *B. campestre* in abundance. Plant 2 showed vascular discoloration at the cotyledon scar and it extended up for 11 mm, but not down the

stem. Isolations yielded *B. campestre*. Plant 3 showed no vascular discoloration and isolation results were negative.

These same three results have been repeated in other experiments. That is, following the development of the cotyledon infection, the disease may progress rapidly up the stem and soon appear in the upper leaves; or it may enter the stem and remain latent; or it may not enter the stem because the cotyledon is abscissed before the bacteria have reached the stem.

FIG. 3.—HEALTHY AND DISEASED CAULIFLOWER COTYLEDONS.

The black-rot infection of the right-hand cotyledon resulted from planting seed from diseased pods. Note the darkening of the veins downward toward the main stem. After affected plants have been set in the field the trouble appears as a systemic wilt. Such plants serve as centers from which the disease spreads extensively. (Much enlarged.)

As regards the mechanism of cotyledon infection, Monteith (11) found that seed soaked in cultures of the organism, then dried and planted, showed infection of the cotyledons. The writer has repeated this experiment several times with similar results. This indicates that the cotyledons can become infected from bacteria attached to the seed coat. However, in addition, there appears to be no question but that the cotyledons are often actually entered by the bacteria while the seed is still in the pod. Thus, when diseased seeds have been sterilized and

crushed in agar, the seed coat frequently separates entirely from the rest of the seed and, in several such instances, bacteria have grown out from the cotyledonary tissue and not from the seed coat, the sterilization evidently destroying the organisms in the seed coat but not reaching the deeper-lying tissues.

The fact that the cauliflower seed pods are highly susceptible to infection and that the lesions penetrate the pods and reach the seeds is believed to be very important from the standpoint of control, since it removes the infection from the class of surface contaminations to that in which the seed coat is penetrated.

Cabbage seed plants were grown in the greenhouse in the same manner as the cauliflower seed plants, except that instead of growing them from seed in the crocks they were headed in the field, stored until the first of the year, and then planted in the greenhouse. They flowered and set seed in the spring and were inoculated in the same manner as the cauliflower. Seven days after inoculation they showed numerous dot-like lesions (Fig. 2B) which, however, never enlarged. Rarely one or more of the vasculars at the suture became infected and occasionally a small lesion developed at the junction of pod and pedicel, but no results were secured which would indicate that local pod infection could serve as an important source of black-rot infection with cabbage seed.

Field inoculation work with cabbage and brussels sprouts seed plants was conducted over several years. Seed pods heavily sprayed with cultures of *B. campestre* developed the pin-point infections but very rarely did any progress beyond this stage. It is concluded that infection of seed of these two plants is chiefly surface infection. These conclusions with respect to cabbage have been confirmed by careful surveys thru the extensive Long Island cabbage seed growing section. The writer has not as yet had an opportunity to inspect cauliflower seed in the field. Consequently, on the basis of this investigation of seed infection, it would be expected that surface sterilization would be effective with cabbage and ineffective with cauliflower.

DEVELOPMENT OF THE DISEASE IN THE SEEDBED

This has been found to vary depending on the source of infection, whether soil or seed, and also on environmental conditions. When healthy seed is sown in a seedbed containing black-rot infection, no evidence of the disease is seen until the plants are about half grown,

and then lesions appear on a few of the leaves. With plenty of rain, these scattering leaf infections multiply until, by the end of the plant bed period, it occasionally happens that a majority of the plants have leaf lesions. Usually, however, the development during the plant bed period is very inconspicuous and badly infected lots of plants may look fine at setting time due to the fact that, while infection has occurred, the disease has not made much progress.

When infected seeds are sown in a plant bed on disease-free soil, the development of the disease is as follows: The infection appears as a cotyledon spot and, since the cotyledons of young seedlings are close together, there is often some spread to adjacent ones. In some years when the seedbed period is dry there is little or no spread from cotyledon to true leaves. Then the infection passes into the main plant stem and is not seen again until three weeks to a month after the plants have been set out into the field. Following a warm wet spell that has induced rapid growth, the disease suddenly appears as a wilt affecting the lower leaves of scattered plants. Such plants, when dissected, show the discolored vasculars extending upward and also downward from the original cotyledon infection. Without knowing the source, one would think the infection derived from the root.

In years when rainfall is abundant during the plant bed period, however, the infection spreads directly from the cotyledons to the first leaves and the leaf infections continue to occur during the entire time the plants are in the bed, and also without interruption after the plants are set. It has been found by repeated field tests that when the weather during the plant bed period is dry the number of plants infected is small and there is little spread of the infection from one part of the bed to another. With rains, however, the infection spreads rapidly to every part of the bed and attempts to prevent spread by means of an unplanted strip of soil 6 to 8 feet wide and by extreme care in working the plants—measures which are 100 per cent efficient with a disease such as black-leg—have repeatedly proved ineffective against black-rot. Hence, weather during the seedbed period determines the early course of the disease and also the amount of primary infection, considering as we have, all plants infected at the time of transplanting as primary and all subsequent field infection as secondary.

The primary plant bed infection, however, does no immediate damage and is so inconspicuous that it is rarely detected. It was entirely overlooked by the early investigators.

FIELD DEVELOPMENT OF BLACK-ROT ON CAULIFLOWER AND RELATION OF ENVIRONMENT TO BLACK-ROT AND STUMP-ROT

Black-rot was originally described as it occurs on cabbage and there the marginal leaf infections and the blackening of the veins are conspicuous features. The symptoms of the same disease on cauliflower are usually so different that, for a time, there was doubt as to whether the disease attacking cauliflower on Long Island was really black-rot. The growers always refer to the trouble as blight, and there is certainly no question but that the symptoms are very similar to the bean bacterial disease which is always called blight. Weather conditions decide what form the disease is to take. In some years, it first takes the appearance of the usual cabbage black-rot with infections occurring chiefly at the leaf margins. Then a sudden period of rain will activate these lesions and, in place of the slow yellowing and destruction of limited areas of leaf tissues, the bacteria spread with extraordinary rapidity and halves of leaves wilt with little or no accompanying blackening of tissues. Slightly later the blackening appears in the midribs, and internal cavities several inches in length are also formed there.

The usual cauliflower blight, however, has quite different characteristics and, on the basis of appearance, might be an entirely different disease. Following the appearance of scattered primary black-rot lesions, either local or systematic thruout the field, there is a sudden and tremendous development of local leaf infections that occur by way of the lower leaf surface with the aid of water drops, either rain or dew. These infections are confined to the lower leaves and the first wave of such infection usually occurs about the first of September on hot humid nights. The lesions are so numerous as actually to cause the affected leaves to dry up with only the midrib and large veins remaining alive. Such leaves soon fall.

On the morning following an infection period, the writer has observed the basal leaves of the cauliflower plants with their entire lower surfaces thickly sprinkled with drops of water and many of these were distinctly yellow. The leaf tissues over these yellow drops already looked water-soaked as shown in Fig. 4. Streak cultures on agar from such drops gave pure cultures of *B. campestre* in some cases and, in others, this organism in mixture. (See, also, Figs. 5, 6, and 7.)

Blight is very descriptive of this form of black-rot. It has been recorded by Samuel (13) as the manner in which the disease affects

FIG. 4.—PORTION OF A BLIGHTED CAULIFLOWER LEAF.
As it appears early in the morning following a warm humid night. When first picked this leaf was covered with dewdrops, many of which were colored yellow by enormous numbers of black-rot bacteria. (Somewhat enlarged.)

Fig. 5.—A Healthy Cauliflower Plant.
At the stage of growth in which blight is likely to become serious in the field. (Much reduced.)

Fig. 6.—A Blighted Cauliflower Plant.
Early stage of the disease. Plant in same stage of growth as the plant shown in Fig. 5. (Much reduced.)

Fig. 7.—Cauliflower Plants in Advanced Stage of Blight.
(Much reduced.)

cauliflower in Australia. It has been noted that cabbage leaves never have drops of water distributed over the lower leaf surface. Instead, they collect at the leaf margin and so also do the black-rot lesions. Once the blight attack on cauliflower begins, it continues steadily until checked by cool weather. The dews appear to supply sufficient moisture so that the spread of infection from lower to upper leaves is a continuous process with dozens of new fleck-like lesions every day. In the absence of other complications, the infection, and drying up and dropping of leaves, continues steadily until checked by the falling temperatures of October. It is then that badly affected plants are often able to grow new leaves and produce a partial crop.

The complication that is liable to come is stem-rot or stump-rot, as it is called. Observations have shown that after the black-rot attack has advanced to the point where the leaves begin to drop from the plants (by which time the infection has gained the main stems) the plants are subject to stump-rot attack, providing favorable weather

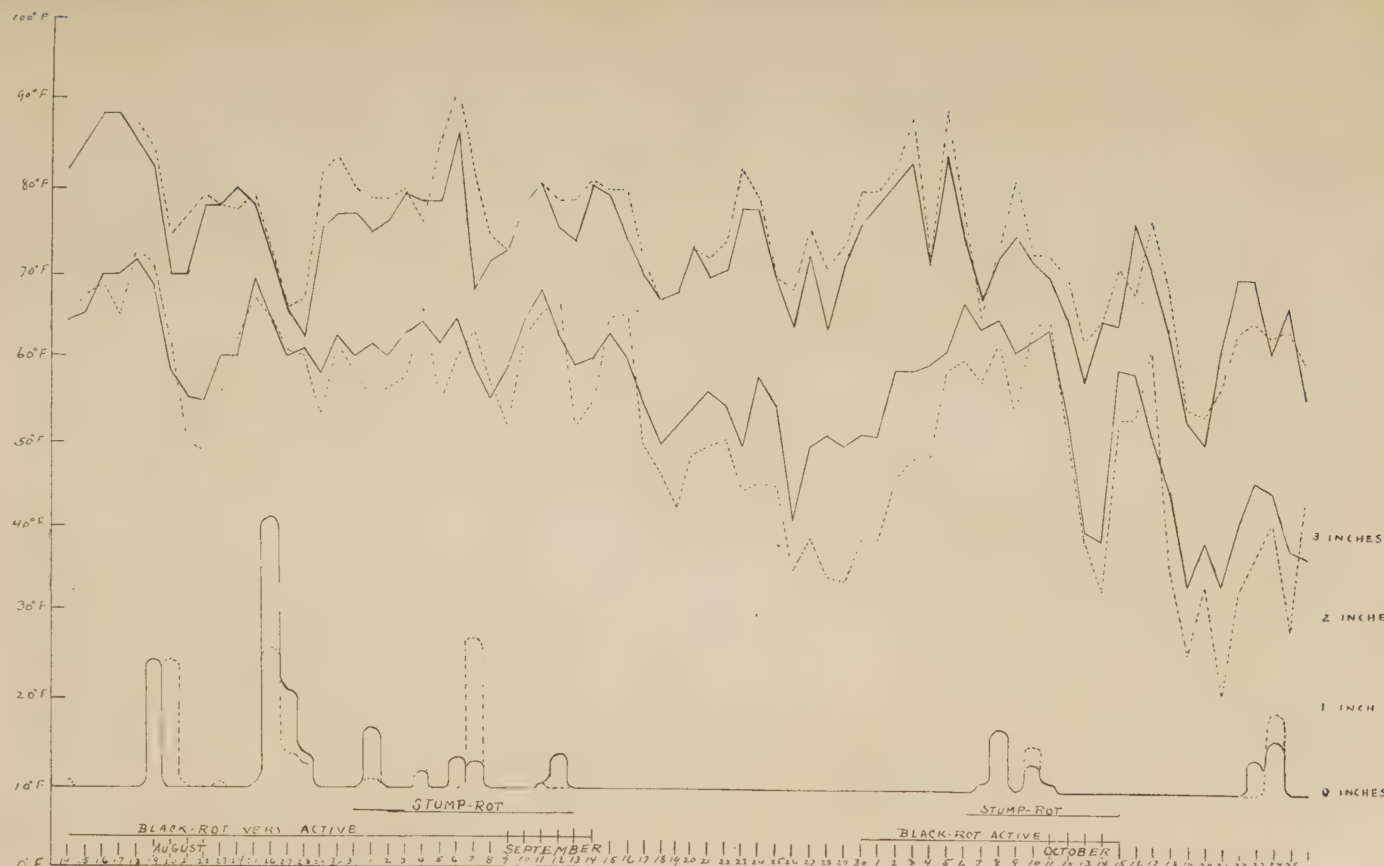

Chart I.—Relation of Maximum and Minimum Temperatures and Rainfall to the Development of Black-Rot and Stump-Rot in 1922. The solid line is the Cutchogue record and the dotted line the Medford record.

conditions are encountered. Stump-rot is only a local name for the soft rot caused by *Bacillus carotovorus* Jones, and this organism is unable to attack without the aid of the black-rot organism in opening the way. However, with black-rot alone to contend with, plants will continue to grow and throw out new leaves indefinitely, but when stump-rot strikes, the entire inside of the stem is soon decayed and the plant is killed. Fields are often destroyed in a few days in this fashion.

Charts I and II trace the relationship of temperature and rain to the development of black-rot and stump-rot in 1922 and 1923, respectively. The data show that in 1922 black-rot became active about August 15 and, favored by rains, was very severe during the next two weeks. The rains continued and stump-rot appeared August 31 and for two weeks following was active and destroyed many fields of cauliflower completely. September 15 to October 6 was dry and stump-rot was not in evidence at all. Rains during the period of October 6 to 10, were accompanied by a second outbreak of stump-rot which destroyed many of the late fields of cauliflower. Turning attention now to temperature, it is to be noted that the minimum (night) temperatures were high during both periods of stump-rot activity and that rainy weather from October 22 to October 25, which was accompanied by low minimum temperatures, did not result in stump-rot. Black-rot was active from August 15 to September 15, during which period minimum temperatures were high. It was dormant from September 15 to 30 with minimum temperatures low, and became active again October 1 with the return of high minimum temperatures even tho there was no rain.

The season of 1923 was relatively dry and there was no stump-rot. Black-rot became active September 3 during dry weather but with a high minimum temperature. There was a wave of infection at this time and the disease continued to spread in the form of a dry blight without the aid of rain until September 20. A rainy period then, plus high minimum temperatures, resulted in a period of intense disease activity which gradually diminished and ceased by October 8, at which time the minimum temperatures had fallen very low. Tho the minimum temperature line rose somewhat a little later and altho there was heavy rainfall, the rise in temperature was not sufficient to activate the black-rot infection. The experiences of these two years have been verified abundantly during five following seasons, and the following conclusions are drawn: Black-rot develops during periods when the night temperatures

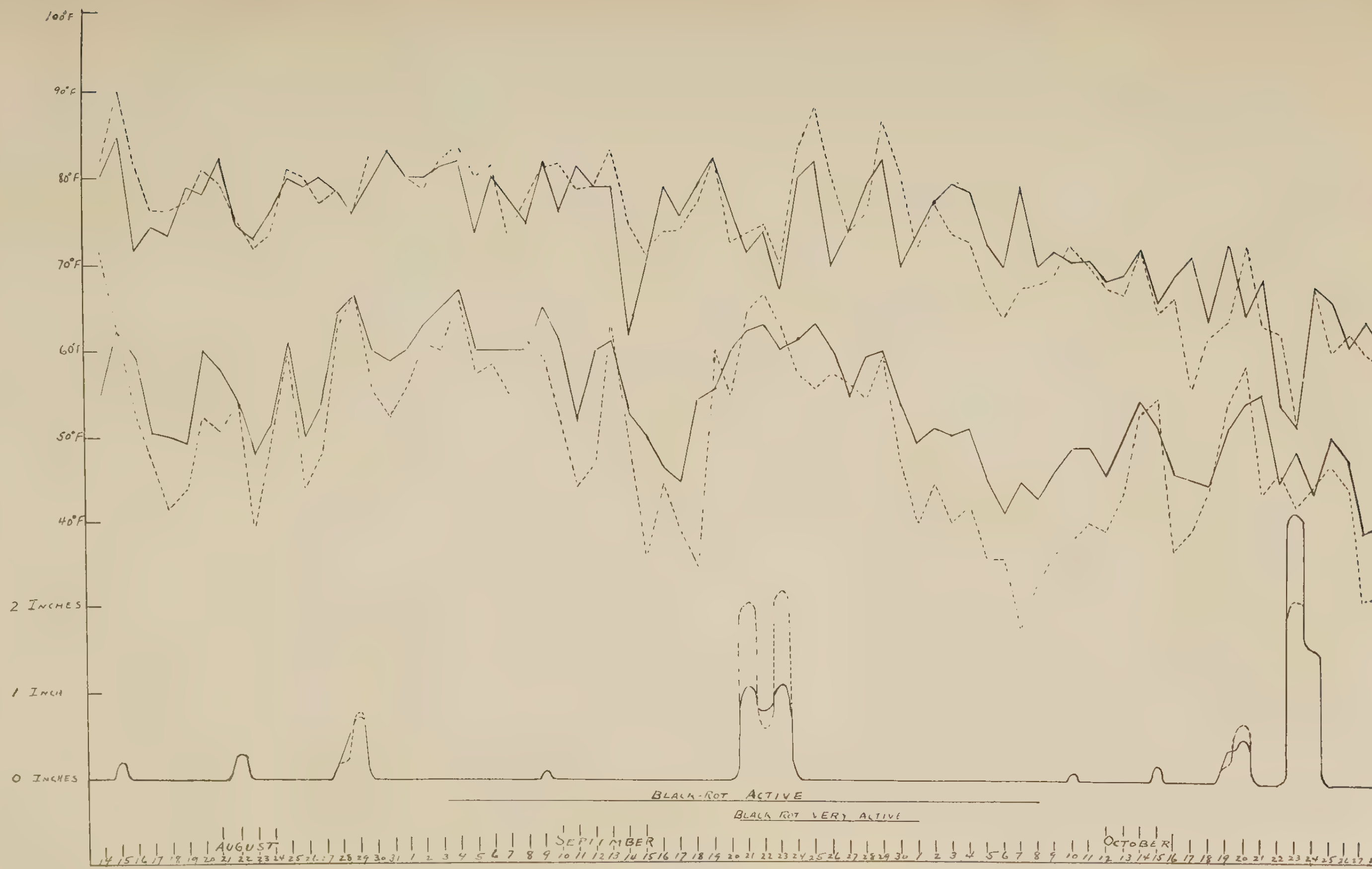

Chart II.- Relation of Maximum and Minimum Temperatures and Rainfall to the Development of Black-Rot and Stump-Rot in 1923. The solid line is the Cutchogue record and the dotted line the Medford record.

(minimum) are above 50°F, and its activity is greatly increased by rain in combination with the high night temperature. Stump-rot is absolutely dependent upon both high night temperature and rain, and it does not appear unless both conditions are fulfilled and also unless black-rot has previously been active.

Since black-rot requires but one condition for activity, high night temperatures, and stump-rot requires this plus rain plus previous black-rot attack, it would be expected that black-rot would be the much more common trouble, and this is the case. In 1928, for example, black-rot appeared early and, favored by rains during the early summer, infection was general and severe. Starting with late summer and continuing thru the fall, however, the weather remained dry, and, when rains did come, cool. Tho the black-rot continued active thruout the dry weather, no stump-rot developed, despite the fears of the growers, and, with the advent of cool weather that checked the blight, many fields, practically abandoned, recovered sufficiently to yield a fair crop.

METHODS OF DISEASE DISSEMINATION

In the seedbed the plants are crowded close together, and Russell (12) has suggested that, "It seems very probable that this disease is sometimes introduced into the plants by insect puncture when the seedlings are in the seedbed. If this should be true, it ought to be a relatively simple matter to check such ravages where the area to be covered is so limited as in this case."

In the course of these experiments, this idea has been tested out thoroly with completely negative results. During wet seasons, as indicated previously, there is a rapid and complete spread thruout a plant bed from any one point of infection. During dry seasons the spread is slow and can be checked by reasonable isolation and care in cultivation. Insects are present in the seedbed in large numbers only in dry seasons. There is every reason to believe that rain spattering is the chief factor concerned in the disease spread thru the plant bed.

The disease appears in the field on Long Island during early August, or late July, depending on the weather and time of setting. The primary field development is either a systemic wilting of scattered plants or occasional local leaf lesions. In either case, the subsequent developments are the same, *viz.*, gradual spread for several weeks and then, during the late summer, an over-night wave of infection, and the fields are, as the growers say, blighted. In some years there are several

such infection periods and, in other years, none that are outstanding. The development of the bacteria simultaneously in hundreds of separate drops of water distributed over a dozen or more leaves per plant and on thousands of plants indicates that the bacteria must have spread from plant to plant and from leaf to leaf, and must have been present on the leaf surface when the conditions exactly favorable to their development arrived, or else must have been spread during the infection period. When an infection period occurs during dry weather, as occasionally happens, immediate dissemination is ruled out. Hence the question that remains to be explained is, How are the bacteria distributed?

Smith (14) states that, "The destruction of insects, particularly the harlequin cabbage bug and the larvae of the cabbage butterfly, should also be thought of in connection with the prevention of this disease. The bites of insects certainly can and do introduce the disease in a certain proportion of the cases, and it seems likely to the writer, as already stated, that the germs are carried from one part of the plant to another and many indirect inoculations brought about in this way, *i. e.*, as the result of germs lodged over the water pores." Russell (12), on the other hand, while noting the possibility of insect transmission, considered that, "It is highly probable that the disease is disseminated by wind more than any other way," and that "the amount of infection that can be traced to such a source (insects) is, however, relatively small and does not begin to compare with the much more important factor of atmospheric dissemination." Brenner (1) confirmed the previous findings with respect to insect dissemination of black-rot, and demonstrated infection by means of aphids. The writer (3), also, was originally of the opinion that this was an insect-disseminated disease.

In approaching this problem of dissemination several lines of attack were planned as follows: First, general field observations on spread, considering different farms and methods of farming followed. Thus, one man will control worms very well, while another will permit them to riddle his crop; one may cultivate frequently and late, and another less frequently and stop early, etc. Because we have had a permanent station in the midst of the cauliflower growing section, facilities for such close observation have been excellent. Second, detailed studies of the spread of disease out from the primary field infections, considering factors such as the effect of distance on the incidence of infection, whether the spread is lengthwise of the rows or without regard to the direction of the rows, etc. Third, attempts to analyze the effect of possible individual factors, such as rain spattering, wind, various insects,

and cultivation, the experiments involving the extensive use of cages and other artificial protections.

Field observations over a period of years have failed to show any relation whatsoever between insect control and the spread of black-rot. On the contrary, moist seasons, least favorable for insect development, were the seasons of most extensive and rapid spread; while dry seasons were seasons characterized by tremendous numbers of insect pests and very slow disease spread. It is possible, furthermore, with insect-disseminated diseases to see a clear connection between the insect infestation and the appearance of the disease in severe form. Thus, with cucumber wilt, it has been repeatedly observed that a dry period during early growth is accompanied by increased numbers of beetles and also by a prolonged season of beetle activity, and that such conditions are always followed closely by severe losses from bacterial wilt. With mosaic disease of the same crop, dry weather during late June and early July permits a free development of the aphids on potatoes and a heavy migration to the cucumbers occurs between July 1 and 15. The outbreak of mosaic follows about 10 days later. Black-rot has shown no such relationship to insect infestation, but instead the reverse conditions of abundant insects and reduced disease or of abundant disease and few insects. The correlation has obviously been with weather conditions just as in the case of late blight disease of potatoes where seasons of reduced insect prevalence are likely to be blight years and *vice versa*.

With regard to cultivation it was noted in the original field survey that the best growers practicing very thoro cultivation were likely to be the ones suffering most serious losses from the disease. Furthermore, farmers with several fields usually had the disease well distributed thru them all while near neighbors might be comparatively free even tho their fields were closely adjoining. It is now known that the chief factor responsible for this is that the plants used to set the different fields of a single farmer generally came from one seedbed. There is much evidence, however, indicating that growers themselves spread disease while cultivating.

The studies of disease spread from primary centers have yielded some interesting suggestions. Two general situations have been observed. In one an infected planting adjoined a healthy one, such a condition resulting from setting plants from two plant beds only one of which was diseased. In the other were observed scattered systematically infected plants early in the season and followed by the spread of disease from these centers.

In all cases where diseased and healthy plantings have been made in the same field the disease has spread freely from the diseased to the healthy, and the rows nearest the diseased plants were always most affected, the amount of infection dropping rapidly as the distance increased. Thus, in one instance, the first row next to the diseased planting showed 63 per cent of the plants infected, the second row but 31.5 per cent, and so on until four rows away at this early season stage there were but a few scattered infections. That such effects are felt to the end of the season is indicated by the following data: Equal numbers of cauliflower plants in the first and second rows next to a diseased planting yielded 13 heads, in the third and fourth rows 19 heads, and in the thirteenth and fourteenth rows 42 heads.

Walker and Tisdale (17) similarly report that the first row of cabbage adjoining a diseased planting was 98 per cent infected, the second 67 per cent, and the twelfth 18 per cent, and concluded that, "It is thus clearly evident that the black-rot organism is readily disseminated in the field by natural agencies."

This question of spread from a diseased block to a healthy block was further investigated as follows during the season of 1923: A lot of plants grown from hot water treated seed in a formaldehyde sterilized seedbed were set out in a solid field block which joined the grower's own planting on one side. The disease appeared in the general planting early and on August 30 many infected plants were present there, while the special block was 100 per cent healthy. The season was dry and the disease did not spread rapidly. On September 17 a single leaf infection was noted on the twenty-third row of the special block counting from the side adjacent to the grower's planting. This single infection, almost 70 feet from the nearest possible source, was also on the tip of an upper leaf where a germ carried by a wind current might be expected to lodge. Under the conditions of this experiment with the weather dry, the rows next to the diseased planting showed more infection than those farther away, but the difference was not so great. Thus, on October 9, rows 1 to 10 had about four times as many infected plants as rows 19 to 28. Had there been more rain, the general spread of disease to the rows immediately adjacent, experience has shown, would have been vastly more intensive and especially would this have been true of rows 1 and 2 (all plants within a radius of 7 or 8 feet). Chewing insects were well controlled and aphids were absent. The spread of disease under the conditions of this experiment must be credited chiefly to natural agencies other than rain, most likely to cultivation and pos-

sibly wind, with the regular heavy dews supplying the necessary moisture for infection.

Further studies of dissemination of disease from the primarily infected field plants indicated intensive spread to immediately adjoining plants. Thus, in one block of 3,000 plants at an early stage of disease development, a careful inspection showed 308 separate black-rot lesions on 159 leaves of 52 plants. Of these 52 infected plants 10 had the disease in the stem and hence can be referred to as primary infections which were the source of all the others. Analyzing further, (a) approximately two-thirds of the other 42 infected plants were adjacent to primarily infected ones and one-third were not; (b) the greatest number of local lesions per plant were on the upper leaves of the primarily infected plants themselves with an average of 17 lesions distributed over 6 leaves; and (c) infections were most numerous on plants immediately adjacent to the systematically infected ones, averaging 6.5 lesions on 3.3 leaves as compared with 2.0 lesions on 1.7 leaves for the plants not adjacent.

As shown by the small number of lesions, conditions in this test were not favorable for the disease owing to dry weather. In fact the disease spread during dry periods is usually scattered compared with that which develops after a warm rain. It is not uncommon then to see well defined circular areas of infection 14 to 16 feet in diameter surrounding the primarily infected plants, and every lower leaf of every plant in this area will have individual infections distributed over the entire leaf-surface without regard to margin or leaf injuries. On the other hand, the infections which occur during less favorable periods are often either marginal or centering about a break in the leaf epidermis as well as relatively few in number. Once blight becomes well distributed and the lower leaves generally infected, however, there is a constant spread of this infection to upper leaves which even dry weather does not check. In such fields are to be seen dry leaves on the ground beneath the plants, old blighted lower leaves with only the midrib and veins alive that are ready to drop, and, at the top, younger leaves with the numerous fleck-like lesions just developing. This condition was common in 1928.

Passing now to some experiments in which an attempt was made actually to measure the efficiency of individual agencies of dissemination, will be discussed, first the results secured with possible insect carriers. The common insects occuring in cauliflower fields during the period of the year when black-rot is active are three species of leaf

feeding larvae, *viz.*, the diamond-back (*Plutella maculipennis* Curtis), the common cabbage worm (*Pontia rapae* Linn.), and the looper (*Autographa brassicae* Riley). These worms were collected from field diseased plants and placed on healthy plants growing in cheesecloth cages. They were also collected and placed in cages containing a diseased plant surrounded by healthy ones, in which case the insects were all placed on the diseased plant and allowed to spread out from this.

The first result of these tests was to prove that the common cabbage worm and the cabbage looper do not move to any extent from one plant to another and that their feeding is confined to the upper portions of the younger leaves. Cages containing these two species of worms showed no black-rot infection that could be attributed to the insects. There were very few infections on the caged plants, both where there were worms and where there were not, while outside the cages the plants showed literally hundreds of infections per plant.

The diamond-back moth larvae behaved differently. In the first place, the worms were more active than either cabbage worms or loopers, and in place of eating steadily they moved around, eating out holes until all the leaves in the cages colonized with this insect were riddled. Counts of black-rot showed more infections than in the check cages. The latter had from 1.1 to 11.6 infections per plant and, in cages infested with diamond-backs, there were from 13.3 to 29.2 infections per plant, indicating more infection in the cages containing diamond-backs, but nothing comparable to disease conditions outside the cages.

In addition to the worms, aphids and thrips were colonized in a number of the cages without in any degree increasing the amount of disease. The outstanding discovery as the result of these experiments was that caging plants protects them almost perfectly from black-rot infection as previously reported (5), and furthermore, that introducing insects from diseased plants, either into cages of healthy plants or into cages containing diseased plants surrounded by healthy ones, did not result in epidemic development of disease.

The ability of the diamond-back larvae to spread black-rot was further tested as follows: Plants growing in large cages were surrounded by others set just outside the cages. Black-rot developed abundantly on those outside but not on those inside, and a little later the diamond-back larvae appeared and riddled the leaves of outside plants. The cloth ends were then removed from two of the cages and, in the course of 4 weeks, the worms had moved in and riddled the leaves of the

caged plants also. No rain other than light showers fell during this period, but tho the leaves of the plants were often bathed in dew and black-rot continued to spread outside, it did not spread into the cages that had been opened. Further evidence that the worms are not of importance as agencies of dissemination will be cited in the discussion of spraying work under control measures. In general, these observations and experiments also indicate that worm injuries affording entrance to the bacteria are, at most, of very minor importance under actual field conditions.

The interesting fact remains, however, that plants grown in cheesecloth cages remained practically free from black-rot, and growing plants in cages is regarded as a standard means of proving insect dissemination. Careful observations, however, have shown that growing plants in cheesecloth cages does much more than exclude insects. The most obvious proof is that the caged plants developed large luxuriant leaves, were twice the size, and weighed more than twice as much as the average outside plants in many of the tests. That these plants were highly susceptible to the disease was repeatedly proved by artificial inoculation. The different growth of the caged plants, of course, merely indicated a marked change in environmental conditions. Even a wire cage which is not as tight as cheesecloth was shown by Burns (2) to reduce the wind velocity to 7.8 per cent of normal and the light intensity to 43 per cent. If, as Russell (12) suggested, wind is an agency of dissemination, then caging practically eliminates this factor. Second, caging with cloth provides a strainer which should be at least moderately effective in catching bacteria, especially if they were borne on particles of soil. Third, the cloth side walls become almost solid walls during rain storms due to the water soaking the meshes, and in this way the plants inside are protected against rain spattering from outside plants. This the writer has tested by staying inside a cage during a hard rain. Fourth, the cage eliminates entirely all contact during cultivation and any possibility of spread by man or cultivation implements.

Thus, caging actually eliminates not only insects but also most of the other possible natural agencies of dissemination. The efficiency of some of these we have been able to prove as follows: Plants were set out (a) along a central aisle that was much traveled in carrying out the routine of the experiments, (b) in side plats given the usual cultivation, and (c) in similar side plats roped in and cultivated with a hoe, being careful never to touch the leaves. The results are shown in Table 1.

TABLE 1.—EFFECT OF PLANT CONTACTS INCIDENT TO CULTIVATION ON THE SPREAD OF BLACK-ROT AMONG CAULIFLOWER PLANTS, FIRST EXPERIMENT.

Location and cultivation	Average number of black-rot lesions per plant
Plants bordering a much traveled path	39.0
Side plats, cultivated in the usual manner	14.0
Side plats, roped in and hoed without touching the plants	9.8

The experiment was repeated later under conditions more favorable for the spread of the disease. The results are shown in Table 2.

TABLE 2.—EFFECT OF PLANT CONTACTS INCIDENT TO CULTIVATION ON THE SPREAD OF BLACK-ROT AMONG CAULIFLOWER PLANTS, SECOND EXPERIMENT.

Plat No.	Number of plants	Treatment	Number of plants with various degrees of black-rot infection*			
			Severe	Moderate	Slight	None
1	62	Plants touched during cultivation	35	23	4	0
2	75	Plants touched during cultivation	38	17	20	0
3	10	Plants not touched	0	1	9	0
4	12	Plants not touched	0	4	8	0
5	36	Plants not touched	0	0	34	2
6	34	Plants not touched	0	1	33	0

* Severe, 100 or more infections per plant; moderate, 25 to 100 infections pér plant; slight, 1 to 25 infections per plant.

The conclusion seems clear that touching the plants while cultivating is responsible for much spread of black-rot. Attempts to measure the effect of rain and wind have been made, but no satisfactory way of eliminating other complicating factors has been found and hence no direct experimental data on the efficiency of these agencies can be offered. On the basis of the field observations of seven years, however, plus the experiments of the nature cited, it is concluded that rain is a very effective disseminator of the disease, spreading it intensively for short distances, and also that the plant contacts incident to cultivation are an important means of spread whereby the infection is carried to different parts of the field. It is also possible that wind plays a part, but under field conditions insect dissemination is a negligible factor. Dew, while not an agency of dissemination, is a valuable aid, especially in the absence of rain when infection would otherwise not occur. On Long Island the cauliflower leaves are often wet with dew until nearly midday.

The importance of these conclusions in relation to the development of an effective program of control is that we now recognize the futility of the often printed recommendation to prevent the spread of black-rot by controlling insects. The ineffectiveness of this procedure has long been suspected by growers. Of more positive value is the new information secured concerning the importance of cultivation in spreading black-rot.

CONTROL OF BLACK-ROT

NUTRITIONAL AND CULTURAL FACTORS

In discussing blight and stump-rot with many growers, the most frequent suggestion made regarding control had to do with fertilization. Some considered manuring a help in the control of the disease, others that heavy nitrogen fertilization was best, and so on. All agreed, however, that none of these things was always effective. The writer has conducted a number of experiments with various fertilizer applications, including manures, and has also had opportunity to study the disease developments in a very extensive series of plats laid out for special nutrition investigations.

The chief conclusion from these studies was that the most rapid-growing plants were always most susceptible to the disease and plants that grew rapidly immediately following transplanting were most likely to encounter weather conditions favorable to disease development and hence were especially subject to black-rot. Liming stimulated growth where land was very acid and increased susceptibility to black-rot. Manuring and high-nitrogen fertilization increased the susceptibility of the foliage to the disease. However, tho it has repeatedly been noted that cauliflower plants grown in limed ground were more subject to blight than plants on ground not limed, and that well-manured, highly fertilized crops were more readily attacked than those not so favored, it has also been noted that when cool weather came in the fall and the disease ceased to be active, those fields that were the best fertilized were the ones that made the most rapid recovery, so that, unless completely destroyed by stump-rot, they often produced a fair crop.

From the practical viewpoint there is no method of fertilization that actually prevents the disease. After the trouble is established the only hope for the grower is cool weather. Good fertilization, however, places the plants in the best condition to make the most of this weather when

it comes; for, unless the recovery is rapid, freezing destroys the plants before a crop is produced.

Cultivation is one of the important ways in which this disease is spread, as pointed out in the discussion of the agencies of dissemination. It is not possible or desirable to avoid cultivating but, during the months of July, August, and September when weather is favorable for black-rot, some care can be exercised not to work the plants when wet with dew. The leaves are often wet until noon, hence by working in the afternoon not only is there less danger of spreading disease but also less damage is done to plants by breaking and tearing the leaves. Observations over a number of seasons support the view that cultivating and working cauliflower during July, August, and September should be confined as much as possible to times when the plants are dry.

REMOVAL OF DISEASED PLANTS AND LEAVES

One of the original control measures recommended for black-rot was the destruction of diseased plants and the picking and removal of infected leaves. Stewart and Harding (15) showed that, for cabbage, this supposedly sound scheme was actually productive of more harm than good. The writer tested out the matter for several seasons in cauliflower fields. In the experiments, conditions favorable to the disease were encountered and, tho the work was done with the greatest thoroness, infections continued to develop with such rapidity that, in each case, the situation was soon out of hand. Notes taken at the time state that it would have been necessary to defoliate some plants and remove many, and this was not deemed advisable. Later developments proved this view correct since the great majority of infected plants, including those with the disease in the main stem, produced fair heads. In this particular year, practically 100 per cent of the infected plants recovered sufficiently to produce marketable heads. Thus the facts that diseased plants are still valuable and that it is not possible to check disease development by their removal make it advisable to eliminate this recommendation, one which has been repeated in numerous bulletins since originally made over 30 years ago.

It is of interest to note that picking off diseased leaves was recently recommended as a control measure for the Phytopthora disease of lilacs. When tried out by De Bruÿn (7), however, the treated plants produced much less bloom than the untreated, so that the loss from treatment was larger than the loss from disease in the majority of cases.

SPRAYING

As a bacterial disease, it might not be expected that black-rot could be controlled by spraying. Bacterial wilt of cucumbers, however, is successfully controlled by spraying against beetles and, in the beginning, it was thought that black-rot might be controlled by spraying against insects, since these, for many years, were supposed to be responsible for its spread. In addition, it was thought desirable to study the value of a fungicide such as bordeaux mixture in seedbed and field.

For two years, special field plats were sprayed with arsenate of lead and soap for worms, but while the treatment gave very effective control of these insects, no control of black-rot resulted since there was quite as much disease in sprayed plats as in unsprayed plats. In addition to worms, aphids and thrips sometimes bother the plants under field conditions and a good many observations have been made in fields treated in whole or in part for these pests. However, conditions which favor aphids and thrips rarely permit the development of black-rot and a connection between these insects and the disease appears impossible. In addition, there was no evidence that spraying for these insects has any effect on black-rot development.

Regarding the use of bordeaux mixture, the first problem solved was that of a suitable spreader. It was found that both soap and miscible oil, when added to bordeaux, caused the spray to spread satisfactorily on cauliflower leaves. Chemical analyses for copper showed equally as much adhering with either, and consequently the oil was used because of greater ease in preparation. The spray was prepared in the power machine by adding ½ gallon of Scalecide to each 100 gallons of bordeaux mixture, allowing the oil to mix with the overflow while sprayer and agitator were running. Smaller lots were prepared by stirring in the oil. Plats in a number of cauliflower beds were sprayed with bordeaux-oil, and from one to three applications were made.

Black-rot was observed in but one of these beds, but it appeared in the fields set from the other beds. So far as could be determined by careful counts, the spraying had no effect on the development of the disease. On the other hand, under some conditions, the spraying was distinctly harmful. Only a 4-4-50 bordeaux was used, but, in two experiments the treated plants were stunted with curled leaf margins and numerous minute dead areas. In most of the tests there was no visible injury, but, to our surprise, it was found that the plants from the sprayed plats, when set out under dry conditions did not live as

well as the unsprayed plants. In general, it was found that little or no injury was caused by spraying during cool weather with plants growing slowly, but rapidly-growing plants in warm weather were susceptible. Since no benefits were secured from the use of bordeaux spray in the seedbed, while frequent losses were sustained, the work along this line was discontinued.

Field plantings of cauliflower were sprayed with bordeaux-oil thru two seasons. A power sprayer, three nozzles to the row, and 4-4-50 bordeaux mixture plus ½ gallon of Scalecide were used thruout. There was a fair development of blight each year and equally as much in sprayed plats and check plats. There was no evidence of any spray injury, but the plants did not head as well in the bordeaux plats. Thus, in one series, four plats sprayed with bordeaux mixture averaged 89.75 heads per plat and two check plats 118 heads per plat. That it was not a question of mechanical injury from the sprayer was proved by the fact that plats sprayed with arsenate of lead and no bordeaux yielded as well as the check plats. Mercuric chloride with gelatine as a spreader was tried out in a preliminary way, but, tho a 1 to 1,200 solution did not burn the leaves, it did check the growth and stunt the plants.

Considering spraying as a whole, there was no evidence that the use of insecticides, either stomach or contact, did anything other than destroy insects. The use of bordeaux in the plant bed and field did not check the black-rot and often resulted in injury to the plants. The unprofitable results over two seasons indicate that spraying, either with insecticides or fungicides has no value as a control measure for black-rot.

DATE OF PLANTING

Observations over a number of years have shown that cauliflower set in late June and early July is much more liable to damage by black-rot than the portion of the crop set after the first of August. Thus, in one test, equal numbers of plants set July 16, 23, and 30 showed 141, 83, and 28 severely diseased plants, respectively, two months later. The writer has found that a good many growers in years past have made a practice of setting late merely to avoid loss from black-rot. The danger of late planting, of course, is that the crop may be caught by freezing weather before it matures. Besides, the question of caring for and marketing the crop makes it impractical to recommend late planting as

a general protection against blight. However, in cases where growers have several fields to set and one of these has been recently cropped to cauliflower so that the chances of encountering the disease are good, it is possible to set this particular field last and thus avoid the disease in hot weather.

RESISTANT VARIETIES

Extensive strain tests on Long Island have shown conclusively that there is no strain of the Snowball-Erfurt variety that is resistant to black-rot, but the more vigorous-growing, coarser types, such as Henderson Erfurt, are able to withstand the disease better than certain of the very highly selected strains, such as Association Snowball. In severely blighted fields the former will sometimes grow new foliage fast enough to make a partial crop, while the latter is stripped to stumps and becomes a complete loss. Pure-line breeding has been carried on over a six-year period and numerous selections from the Snowball-Erfurt variety have been tested. Certain strains, more resistant than the original variety, have been secured, but the increased resistance was not great and, unfortunately, was generally coupled with poor-head type. These strains were finally discarded as unprofitable.

During the winter of 1923, a cross was made between the cauliflower and the collard, which plant had previously been found quite tolerant to black-rot. In the following years these crosses were selfed and selected for heading types and also backcrossed on cauliflower again. Tests of various selections showed that some were as susceptible as the cauliflower and that others showed varying degrees of resistance up to those that were as resistant as the original collard. Certain of the best types were selected in the field in 1928, seeded in the greenhouse during the winter, and grown in field plats in 1929. The possibility of securing a blight resistant cauliflower from this material appears good, but this will be a matter requiring several more years of work.

WEEDS AS SOURCES OF BLACK-ROT

The elimination of wild mustard or other cruciferous weeds as a control measure for black-rot has been recommended. Black mustard is a common weed on Long Island, but it is very rare that these plants show black-rot infection even when growing in badly blighted cauliflower fields.

This is quite different from the condition Smith (14) reports and is probably due to a difference in the environment. Most Long Island

farmers control weeds exceptionally well and there are few fence rows to serve as sources of contamination. Close investigation has not indicated that weeds are an important source of black-rot infection, but it would be the part of safety to avoid locating the plant bed in an area where mustard is found growing. Club-root is a disease that is quite likely to be encountered in such locations.

SELECTION OF SEEDBED SOIL

One of the most important sources of black-rot infection under Long Island conditions is the seedbed soil. Careful investigation has shown that even a trace of disease encountered in the seedbed soil is liable to contaminate an entire plant bed and ultimately all of the fields set from this plant bed; the reason being that the plants growing closely together in the seedbed offer exceptional opportunities for disease spread. It has been proved by carefully conducted experiments that the black-rot infection in the soil can be destroyed very readily by sterilization, either with steam or formaldehyde. However, where plants are produced in field beds occupying large areas, as on Long Island, neither method is practical except as a last resort.

Careful rotation as a method of securing uninfected seedbed soil has been thoroly tested and found satisfactory, provided certain precautions are faithfully followed. The first and most important of these is that the seed bed be located in a field no part of which has grown a cruciferous crop (cabbage, cauliflower, brussels sprouts, or rutabagas) for the six years previous. It is not uncommon for a field to be planted in part to potatoes and in part to cauliflower and brussels sprouts, and, not infrequently, growers locate a plant bed the following year in a portion planted to potatoes the year previous. Even tho this land may never have grown a cruciferous crop, it is not suitable for a seedbed, since in plowing, and more especially in harrowing a field, infection is carried from one part to another. Hence, the recommendation that the seedbed be located in a field no part of which has grown crucifers for the past six years.

Brussels sprouts, owing to their ability to live over winter, are especially dangerous and, in a good many cases, black-rot infection has been traced to a nearby planting of this crop. On the other hand, many observations show that plantings of crucifers fairly near the seedbed area are not dangerous if the two are in separate fields, thus avoiding the danger of spread of infection during plowing and fitting the land.

Occasionally, drainage water is a source of infection, but this only occurs when a bed is located in a low area that receives surface water from a last year's field. Contamination of the seedbed soil with refuse containing old cauliflower, cabbage, or brussels sprouts material also happens occasionally and beds located near the buildings are liable to suffer in this way. Since the owner is not always sure where such materials have been dumped, it is a good plan not to locate beds close to the buildings. A number of complete crop losses from disease were traced to infection contracted in this way.

Manure is one of the best fertilizers for the plant bed and many growers consider it necessary. The writer, however, has grown many thousands of the very best plants without any manure and only a very light application of fertilizer, and so does not consider manure essential as a food. It is often contaminated thru the feeding or dumping of old cabbage or cauliflower refuse and is not an uncommon source of infection in the plant bed.

Our experience is that no precaution to insure a healthy seedbed location should be omitted. The area involved is small and its importance cannot be overestimated. Numerous crop failures with heavy financial losses are due to growers taking chances in locating their seedbeds.

SELECTION OF FIELD SOIL

It is important that the field soil be free from black-rot infection, but it is not necessary to take the extreme precautions just described in connection with the seedbed. It has been proved that the infection survives the winter freely in plants that live over, such as brussels sprouts. It has also been proved that some infection survives one winter in the soil of cauliflower fields. Consequently, following one crucifer with another is not advisable. If it is necessary, however, and occasionally it is, then by all means follow cauliflower with brussels sprouts or cabbage, and not the reverse, for two reasons. First, the cauliflower crop, which never survives the winter, carries over much less disease to the next year than the brussels sprouts or cabbage, and, second, the latter crops are much more resistant to black-rot and so the loss is not as great if the disease does develop. In general, our tests with cauliflower after cauliflower have shown that too much black-rot lives over to make continuous culture advisable. Even a single year's rest brings a great improvement and, where healthy plants have been

set on land that was cropped the second year previous to cauliflower, the fields were quite free from black-rot. Other long-lived disease infections, especially club-root, make such a short rotation as this inadvisable, however, and the safest plan is either a three-, four-, or five-year rotation for the main field, the length depending on the rotation system and the other crops that can be grown.

For Long Island growers who have a limited amount of light land that they have limed especially for cauliflower, a three-year field rotation is recommended. Obviously, the man who controls diseases most thoroly has less trouble to starve them out of his soil and so is in position to follow the shortest rotation with satisfaction, while the grower in the habit of growing badly diseased crops is every season piling up future trouble, and extreme care, in every way, coupled with a long rotation, are essential for him.

SEED TREATMENT

The mercuric chloride soaking treatment was not tested out under field conditions by Harding, Stewart, and Prucha (8) because, in their experiments, planned with this in view, the disease failed to appear. The method, however, has been widely accepted and several reports testifying to its effectiveness in destroying seed-borne black-rot infection on cabbage are in the literature. In view of this, the negative results secured with this treatment when used on cauliflower on Long Island seemed most puzzling.

As explained under the discussion of seed infection, however, we now know that cauliflower seed pods are highly susceptible to local infections and that the organism therefore penetrates the seed coat, while, with cabbage, this is rarely the case. Consequently, with cauliflower, the disease is internally seed-borne. Secondly, we found that the cauliflower was so much more susceptible than cabbage that the infection must be practically eliminated to give results, even the slightest trace of infection being sufficient to multiply and destroy a crop with favoring weather. As a result, therefore, the need for a more efficient treatment for cauliflower is quite understandable. Previous work with black-leg has shown that the mercuric chloride treatment was satisfactory provided conditions were not especially favorable for the disease, but that the hot water treatment was more efficient and, under favorable disease conditions, far more effective in protecting the crop.

Hot water treatments against black-rot were tried out, both in the

laboratory and in extensive field tests, and it was found that the standard treatment (25 minutes at 122°F), while excellent for disease control, was too severe for cauliflower. Many lots of seed, when given this treatment, dropped off in germination rapidly tho the immediate effect was not noticeable. A shorter treatment of 18 minutes at 122°F was adopted after extensive tests both as to its effectiveness in disease control and as to its safety. This method of seed testing and treating has been fully described by the author (6) and need not be detailed here other than to state that this procedure has now been in successful commercial operation on Long Island for several years without change. The writer has also accumulated a very large volume of data as to the effect of various chemical soaking treatments, heat, and heat-plus chemical soaking treatments on cauliflower seed germination and disease control which will be presented in a separate technical publication at a later date. (See Figs. 8 and 9.)

Fig. 8.—Badly Blighted Cauliflower Plants.
Grown from diseased seed untreated. (Much reduced.)

The effectiveness of the 18-minute hot water treatment under field conditions has been excellent. In 1926 and 1927, the writer treated almost a thousand pounds of cauliflower seed each year, using this method, and except where precautions with regard to soil infection or other outside sources of infection were not observed, there was marked control of black-rot. The writer has also grown plats of cauliflower on

the farms of different growers during the seasons of 1928 and 1929, using this treatment with equally excellent control of the disease.

FIG. 9.—HEALTHY CAULIFLOWER PLANTS.

Grown from some of the same lot of seed as the plants shown in Fig. 8, but the seed was given the hot water treatment. (Much reduced.)

In addition to using the hot water method of seed treatment for cauliflower, one further precaution has been found essential and that is to treat all lots of cabbage and brussels sprouts seed as well as cauliflower. It has been amply proved that a small sowing of brussels sprouts seed can thoroly infect an entire cauliflower plant bed, and furthermore that brussels sprouts, for example, may be the source of the disease and still suffer but little damage, while the cauliflower is seriously injured or even a complete loss. In treating seed it is of the utmost importance, then, to treat every lot, however small, since each different lot of seed is to be regarded as a possible source of infection and effective work requires that all possible sources of infection be guarded against. The regular hot water treatment of 25 minutes at 122°F is recommended for brussels sprouts and cabbage seed, since, as reported previously (6), this is more certain than the mercuric chloride treatment.

A PROGRAM OF BLIGHT CONTROL

As a result of the experiments reported here it is certain that no grower can hope to control black-rot or blight without exercising the greatest care and going to considerable bother, but it is equally certain that, for any grower who wishes it, the means of control are now available. The disease spreads with extreme rapidity once it gains a foothold, and effective control consists in preventing it from gaining a foothold early in the season. If plants are free from infection up to the time when they are set out, it is practically assured that the disease will cause no loss. Growing healthy plants requires healthy seed and seedbed soil. To insure the first, all seed should be hot water treated before sowing. To insure the second, the precautions outlined in the previous discussion with regard to seedbed location should be followed faithfully. These two measures are effective and offer a practical way whereby any grower can avoid loss from this disease.

SUMMARY

Black-rot or blight has been a very troublesome disease on Long Island for years. The situation became so serious that, in 1922, many were of the opinion that the cauliflower industry was doomed, owing to the repeated heavy attacks of this trouble and the accompanying stump-rot. The susceptibility of the cauliflower plant to this disease is such that it is often destroyed completely under conditions where cabbage or brussels sprouts in the same field are but little injured.

Observations over a period of 7 years show that black-rot is liable to break out any time when the night temperatures are well above 50°F. Rain, while not essential, greatly increases the rapidity of spread and also stimulates the disease in the plants to renewed activity. Stump-rot only appears as a secondary development of black-rot and requires both high temperatures and moisture for its development.

The symptoms of black-rot on cauliflower are very different from those on cabbage. The infections occur over the entire leaf instead of along the margins and, depending on dry or wet weather, the disease may be either a dry blight or a wilt.

The causal organism lives over freely on diseased cabbage or brussels sprouts plants that survive the winter, but it has never been recovered from dead cauliflower plants. It does, however, carry over at least one season in soil. It is readily destroyed either by steam or formaldehyde sterilization.

Cauliflower seed pods are highly susceptible to infection and, 7 days after spray inoculation, the younger pods show numerous water-soaked lesions. Under similar conditions the minimum incubation period for tender young leaves is 12 days.

Seeds produced in diseased pods mature normally but many carry the infection both externally and internally. Infected seed germinates normally but the disease appears as cotyledonary lesions and ultimately becomes established in the main stem.

In the plant bed the spread of black-rot depends on whether infection comes from the seed or the soil, and on the weather. Often the spread is so rapid that the bacteria are carried from a single point and infect scattering plants thruout a large bed; but, owing to the short time the plants remain in the bed, there is opportunity for little more than this initial spread, and the conspicuous crop damage all occurs later in the field.

Infection in the plant bed, however, is essential for the development of destructive disease attacks in the field since, otherwise, the disease does not get an early enough start to become widely distributed before the cool weather of fall arrives.

Insects are not responsible for the spread of black-rot under field conditions. Instead, rain and the men working the crop are the major means of spread. Consequently, thoro poisoning of worms gives no protection, but care to avoid cultivating diseased fields more than is necessary, especially when the leaves are wet, helps somewhat.

Spraying with bordeaux mixture, special methods of fertilization, and hand picking and destruction of diseased leaves and plants are not effective means of control. Disease-resistant varieties offer promise for the future, but are not available now.

Excellent control of this disease may be secured, first, by using the utmost care to locate the plant bed in a disease-free area and, second, by sowing there only seed that has been hot water treated.

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